South China University of Technology

Workshop, 10 December 2015

Use-Inspired Mobile Robots R&D: A New Zealand Perspective

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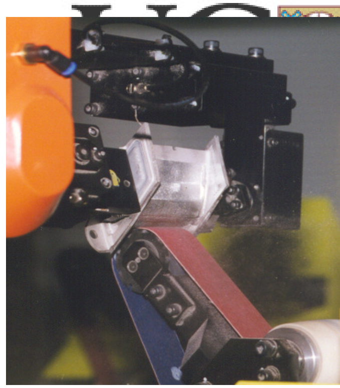
Agenda

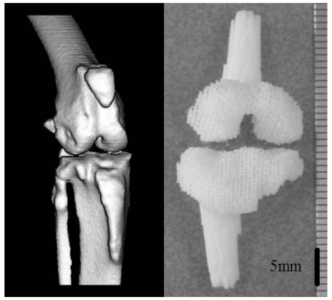
- Introduction
- UC Rocketry
- Wall Climbing Robots in Action
- Mobile Robots in Agriculture
- Conclusions

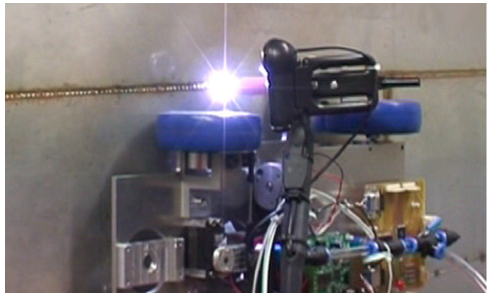
Mechatronics@UC

Instrumentation and Automation

- Manufacturing automation
- Additive manufacturing
- Tissue engineering

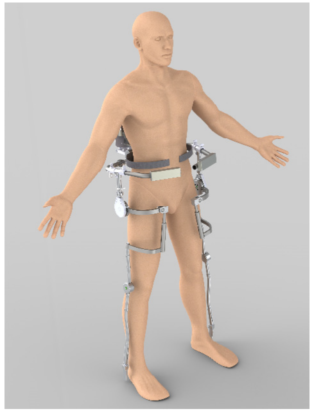


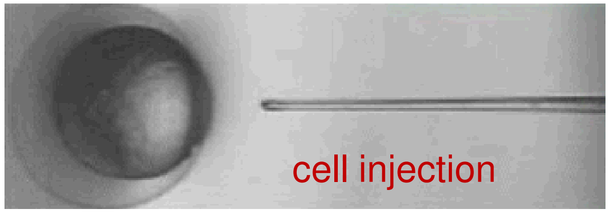




Bio-mechatronics

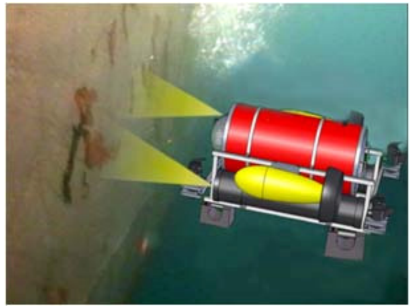
- Assistive devices
- Bio-micromanipulation

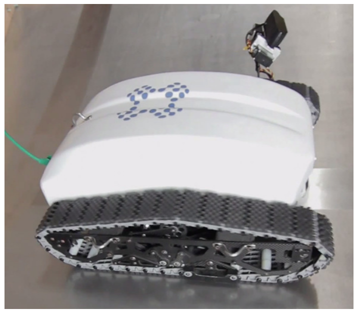


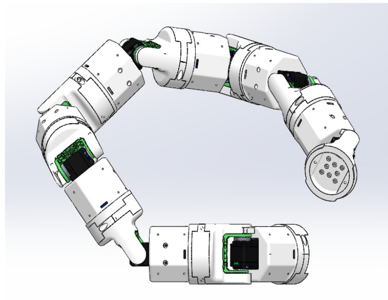


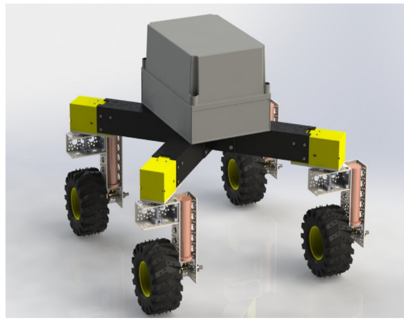
Mobile Robotics

- Unmanned aerial vehicle
- Underwater robot
- Wall-climb robot
- Land based robot









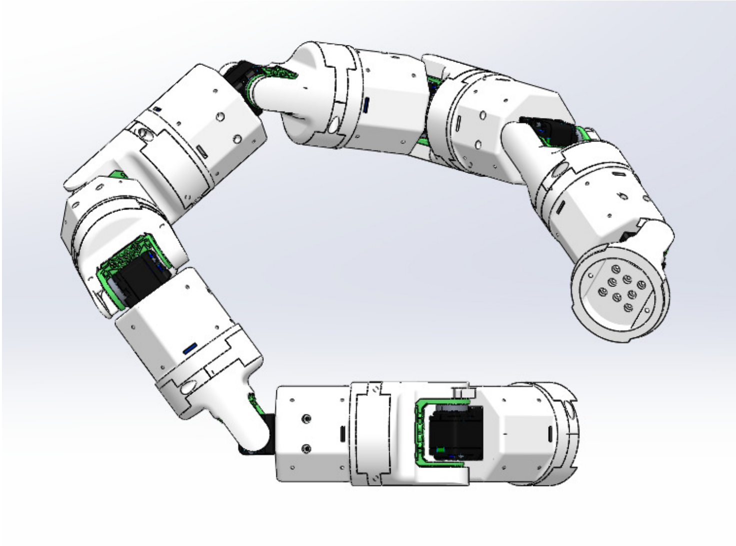
Biomemetic Snake Robot

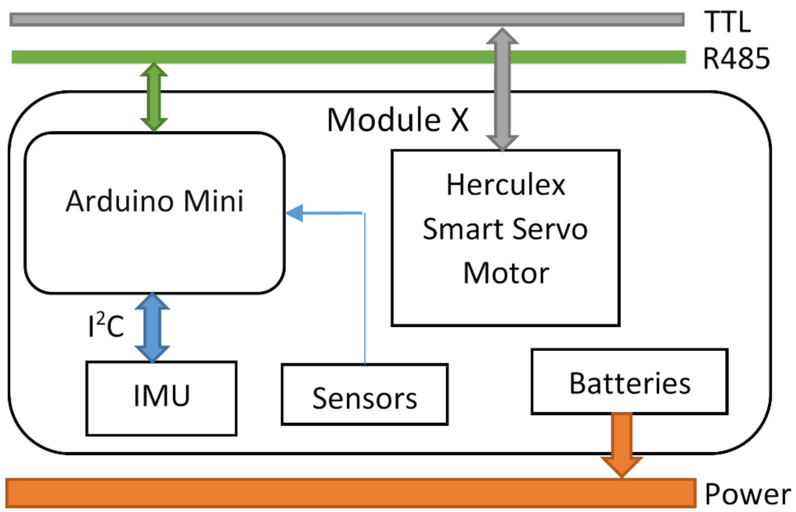
Innovation

- Modular design, scalable
- Robust and resilient (fault tolerant)
- Gait parameterisation
- Agile biomimetic locomotion:
  - Lateral undulation
  - Linear Progression
  - Lateral Rolling
  - Turning
  - Side Winding

Potential Applications

- Search and Rescue
- Structure & bridge inspection
- Understructure inspection





UCOR – UC Omnidirectional Robot

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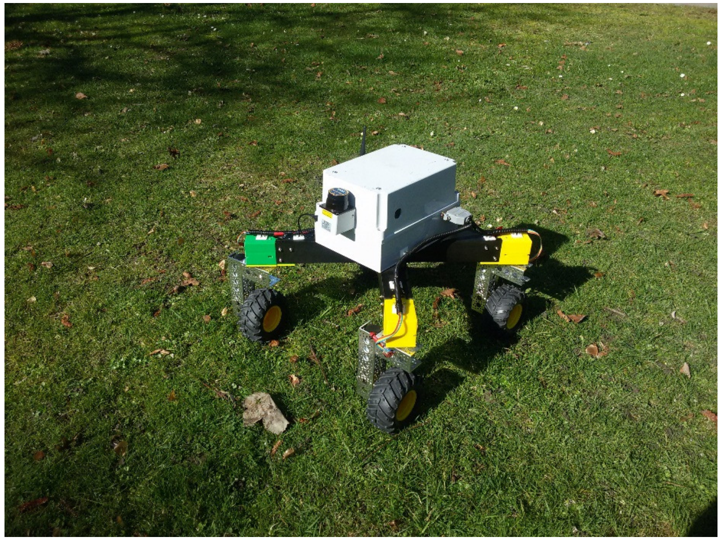
Innovation

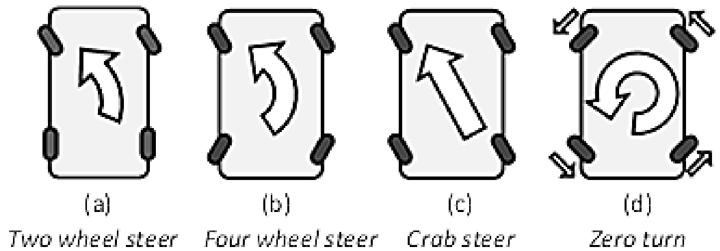
- Independently driven and steered wheels
- Slope (20% grade), rough terrain.
- Precision maneuverability
- Remote, semi and autonomous control

Potential Applications

- Transport of tools/sensors
- Crop inspection & harvest
- Weed detection and control
- Survey Mapping

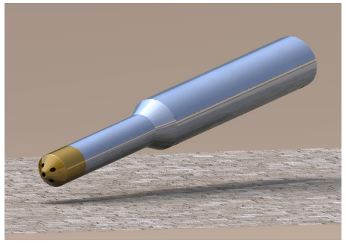
Video

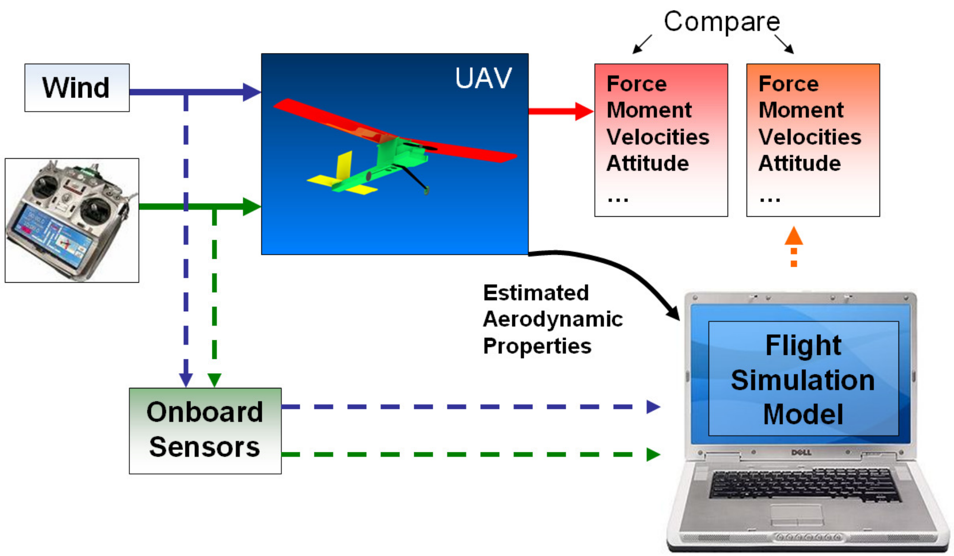




FDM Validation with On-Board Instruments

- Equipment used
  - 2.4 meter wing-span gas powered RC plane
  - GPS base station
  - Inertia navigation system
  - Servo pulse acquisition device
  - Wind speed sensor
  - Data logger
  - Wind tunnel





IRMAC - Integrated ROS based Robotic Modelling And Control

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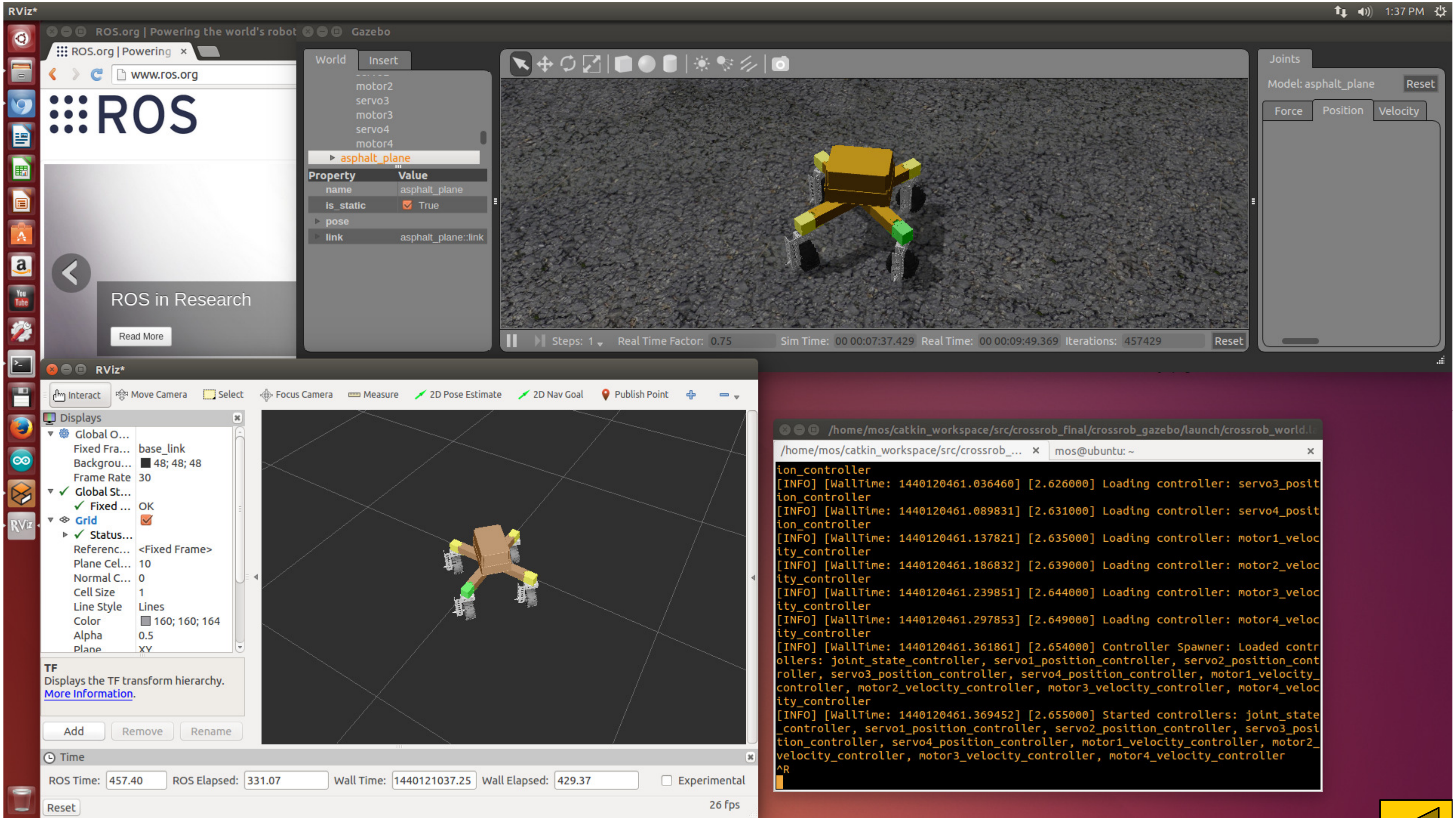

UC Rocketry Program

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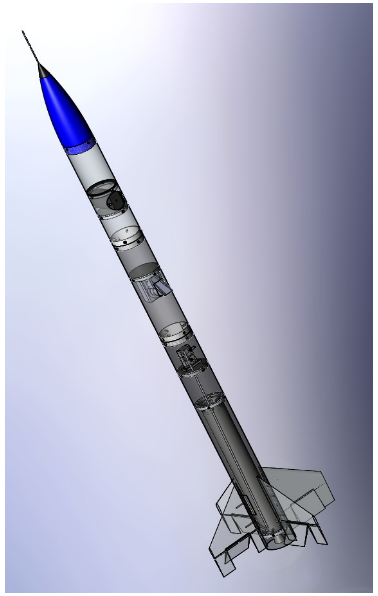
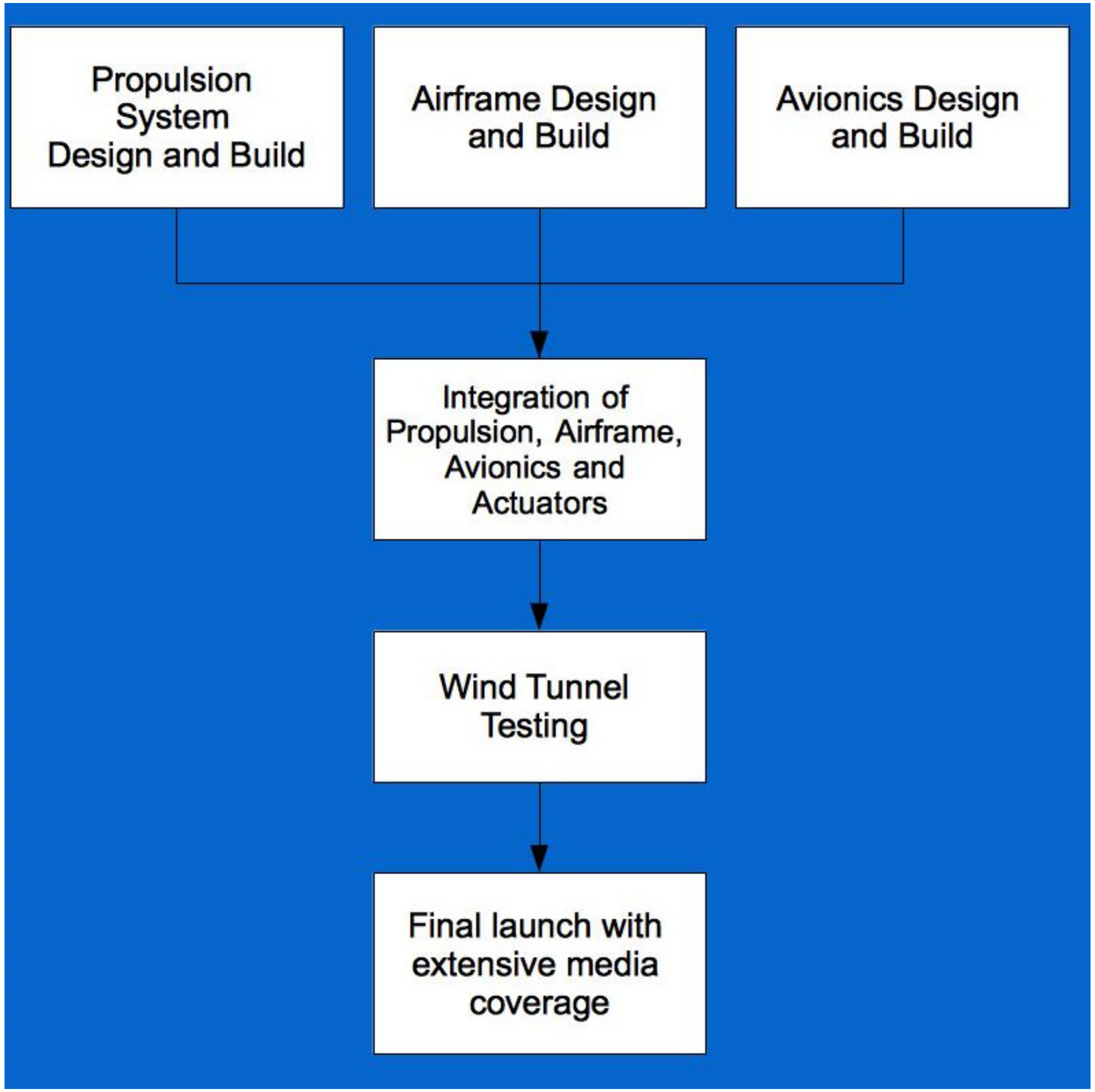
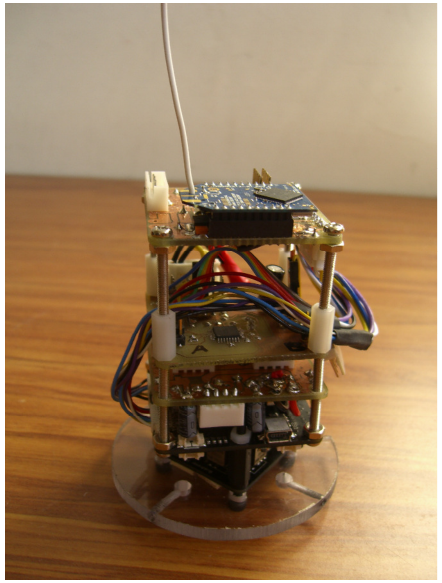






Propulsion

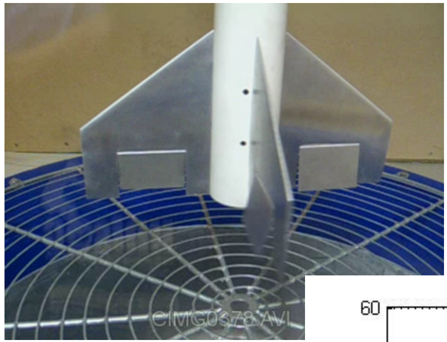
Video: static propulsion test

- Stress analysis
- Isentropic nozzle flow theory
- Propellant burn properties
- Motor customisation
- Performance testing

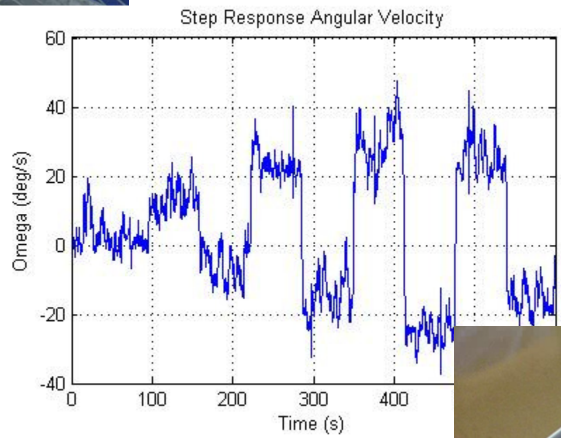
$$\text{Expansion\_ratio} := \left[\left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \left(\frac{p\_exit}{p\_chamber}\right)^{\frac{1}{k}} \cdot \left[\frac{k+1}{k-1} \cdot \left[1 - \left(\frac{p\_exit}{p\_chamber}\right)^{\frac{k-1}{k}}\right]\right]^{\frac{1}{2}}\right]$$

Rocket Dynamics and Disturbance Modelling and System Identification

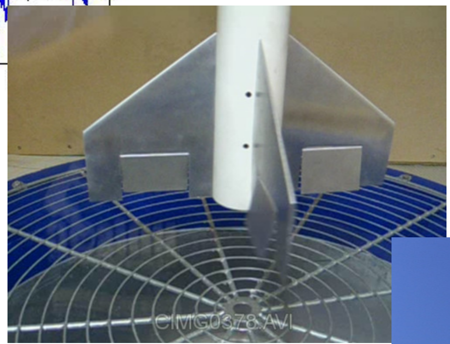
What can go wrong



Wind Tunnel
Dynamic Response



MATLAB
System Identification



Wind Tunnel
Controller Validation

Implementation

Final Launch

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Rocket Lab in deal with US aerospace firm (staff.co.nz 01/12/2010)

Rocket Lab was founded by Mr Peter Beck and Mark Rocket.

Launched Atea-1, a 6-metre long, 60 kilogram rocket into space in November 2009, believed to be the first private rocket launched in the Southern Hemisphere.

It has since won contracts from the US Government, the Australian defence force and major defence contractor Lockhead Martin, although the latest deal was the largest to date.

Rocket Lab's new partner, L2 Aerospace, is headed by retired four-star General Lance Lord, the former head of the US Air Force Space Command, where he was in charge of 47,000 military personnel and staff.

Novel Wall Climbing Robot in Action

ScienceAlert
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Wall-climbing robot breakthrough

Sunday, 19 August 2007

University of Canterbury

Robotic research at the University of Canterbury has climbed new heights with the development of a wall-climbing robot.

The robot has been developed by a team of researchers lead by Associate Professor XiaoQi Chen in the University's Mechanical Engineering department.

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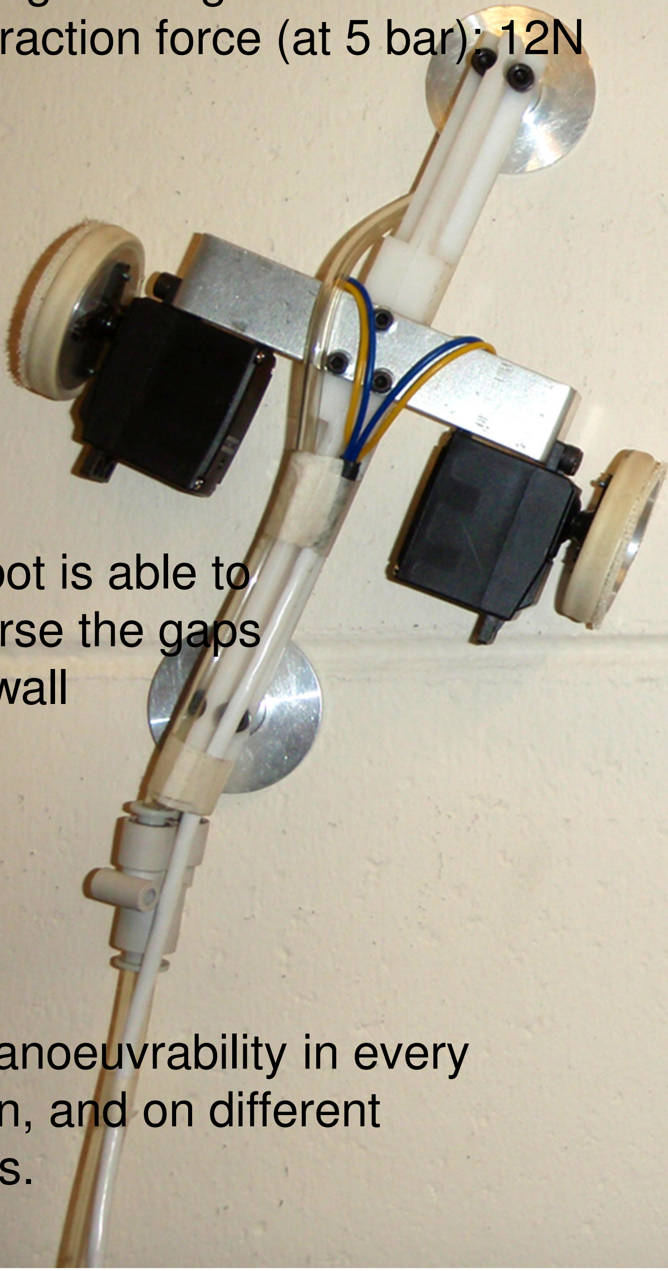
Engineers design robot capable of climbing walls (8/21/2007)

A journey of wall climb at UC

- 2006: Initiated the research
- 2007: Non-contact wall climbing prototype
- 2010: Invert Robotics Limited was formed.
- 2011: Untethered wall climbing robot.
- 2012: Completed its first job inspecting a milk powder dryer for Westland Milk in Hokitika
- 2012: **Received MSI Best Start-up Award**

UC Wall-Climbing Robot – Performace (2009)

Total weight: 234g
Max attraction force (at 5 bar): 12N



The robot is able to transverse the gaps on the wall

High manoeuvrability in every direction, and on different surfaces.

Video

Additional 500g weight is lifted.

BLOGS // AUTOMATON

Robot Uses Supersonic Jets of Air to Stick to Almost Anything

POSTED BY: EVAN ACKERMAN / TUE, MAY 24, 2011

There are all kinds of ways to stick to a surface, but one of the simplest is to use a gripper that operates on the Bernoul principle. All the Bernoulli principle says is that as a liquid moves faster, its pressure decreases. For the purpose of a robotic gripper, air counts as a fluid, and if you squirt air out around the edges of a circular gripper fast enough, it'll star to generate a vacuum force that's strong enough to grab things *without the surface of the gripper actually needing to touch them*. The major upside of this technique is that you get a **non-contact** vacuum grip, so it's useful for grabbing stuff that's sterile or fragile.

Untethered Wall Climbing Robot
无拴线爬壁机器人

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INVERT ROBOTICS

6 person team, 6 hour inspection process with safety concern

1 operator, 0.5 hour inspection, operating outside tank

Industrial Drive

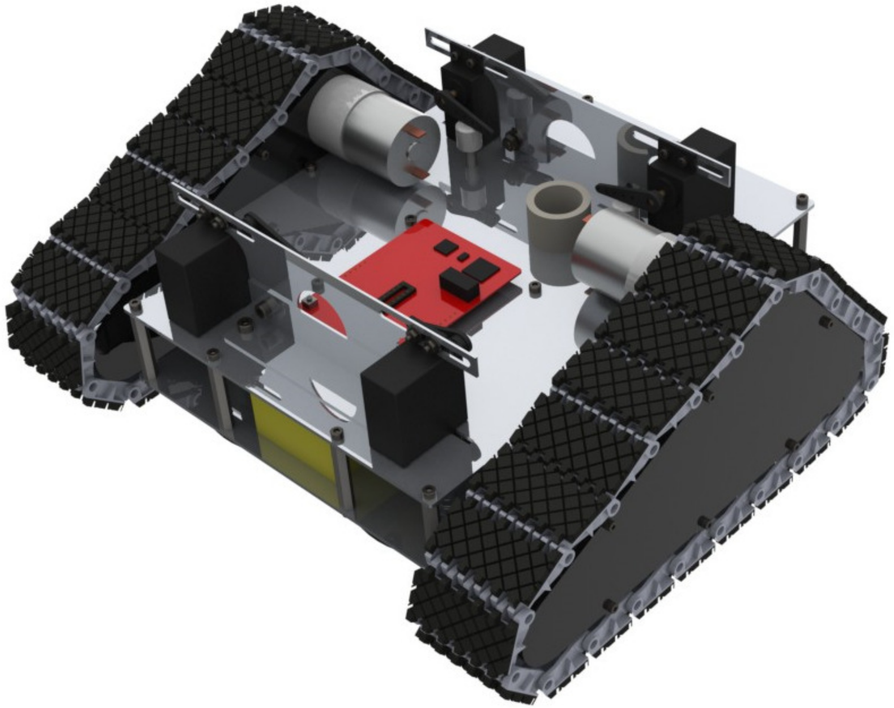
Design an un-tethered robotic device

that can achieve the following:

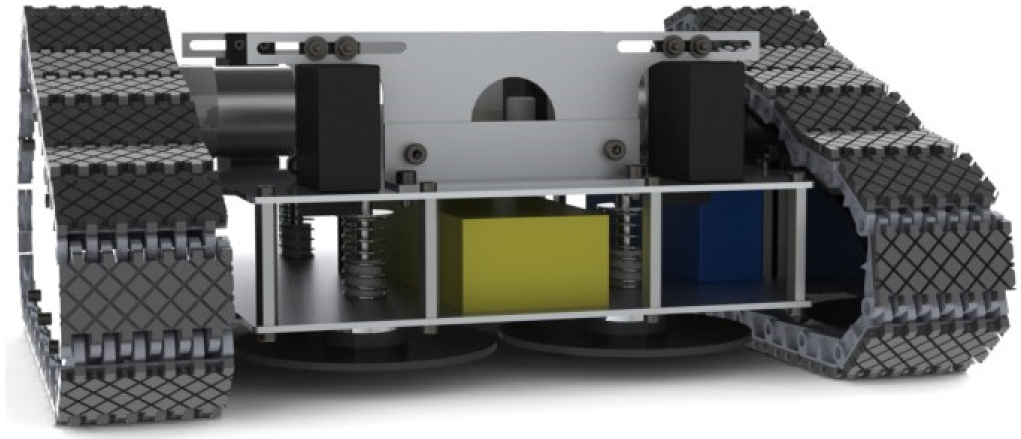
- Reliably stick to the inner tank wall
- Run continuously for 30min
- Must not damage or contaminate tank surface
- Carry a 1Kg payload
- Minimum speed of 0.3m/s
- Survive a 12m fall onto concrete

Innovation

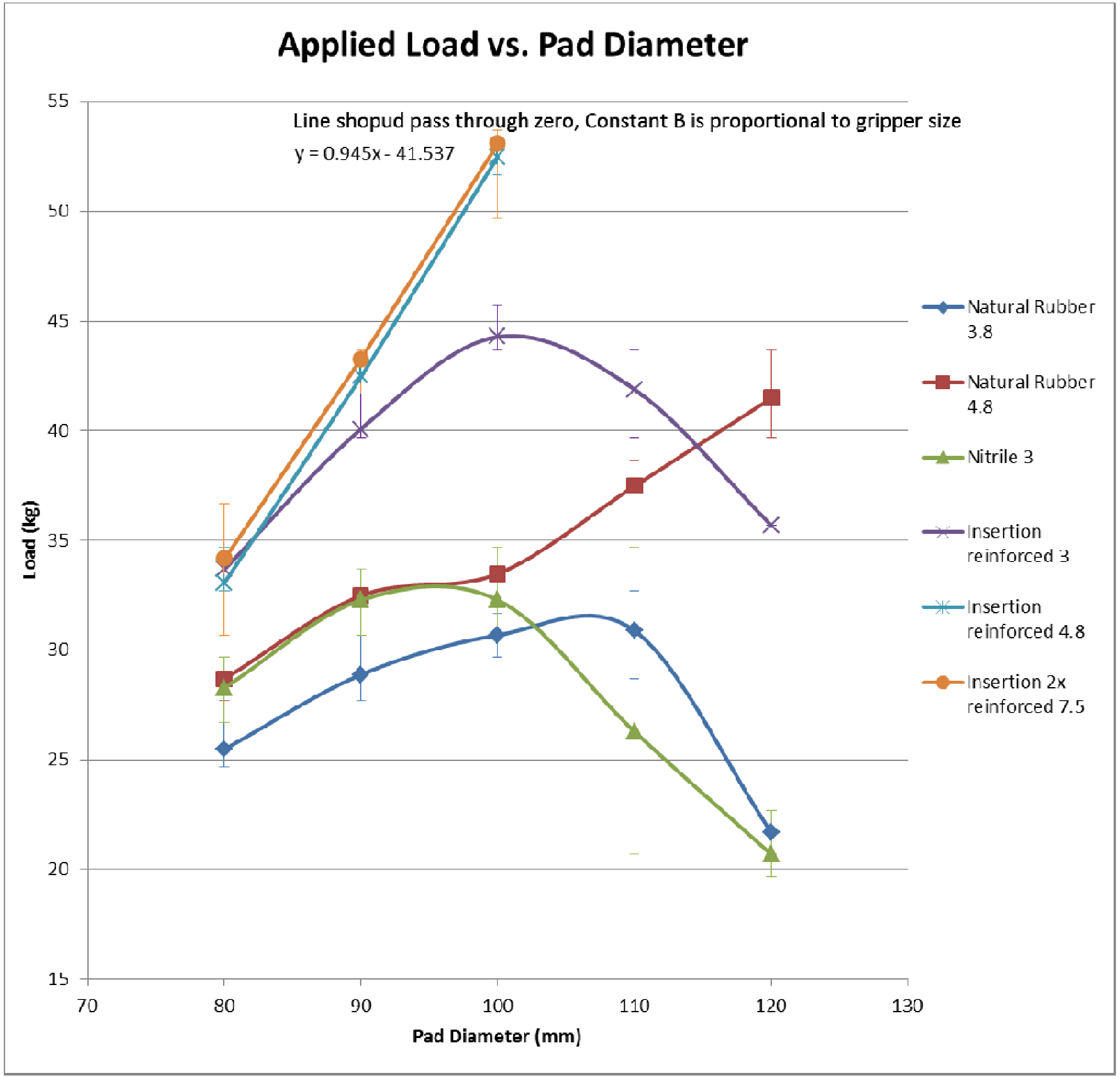
- Active primed suction
- Untethered
- Onboard sensing and control
- Force feedback control
- Energy efficient, run continuously for hours



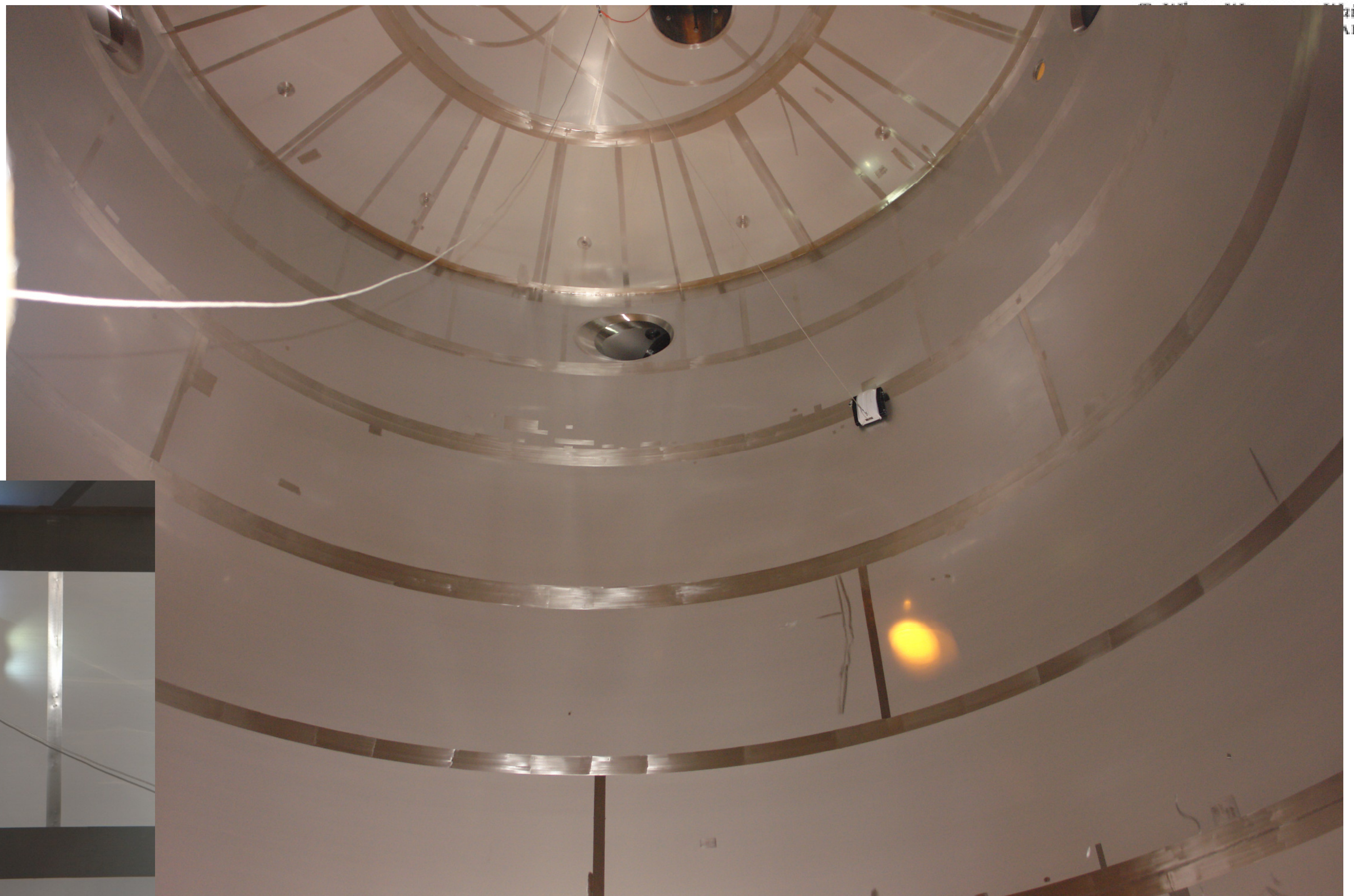
Video: untethered



Pad Reliability Test



Robot inspection in action

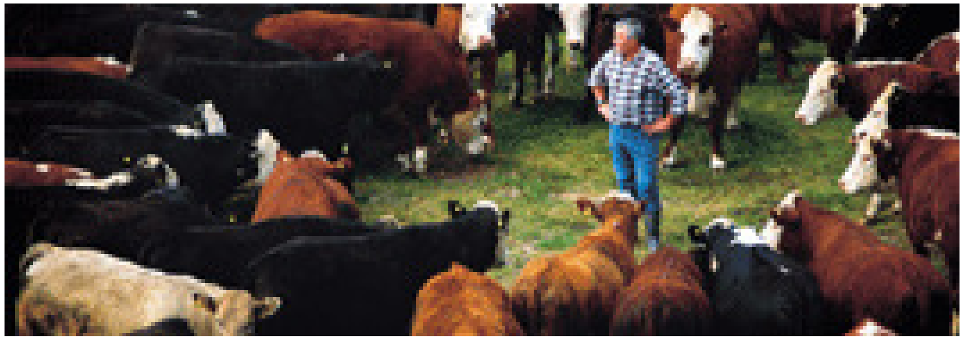


Video: Working system completed with instrumentation

Mobile Robotics in Agriculture

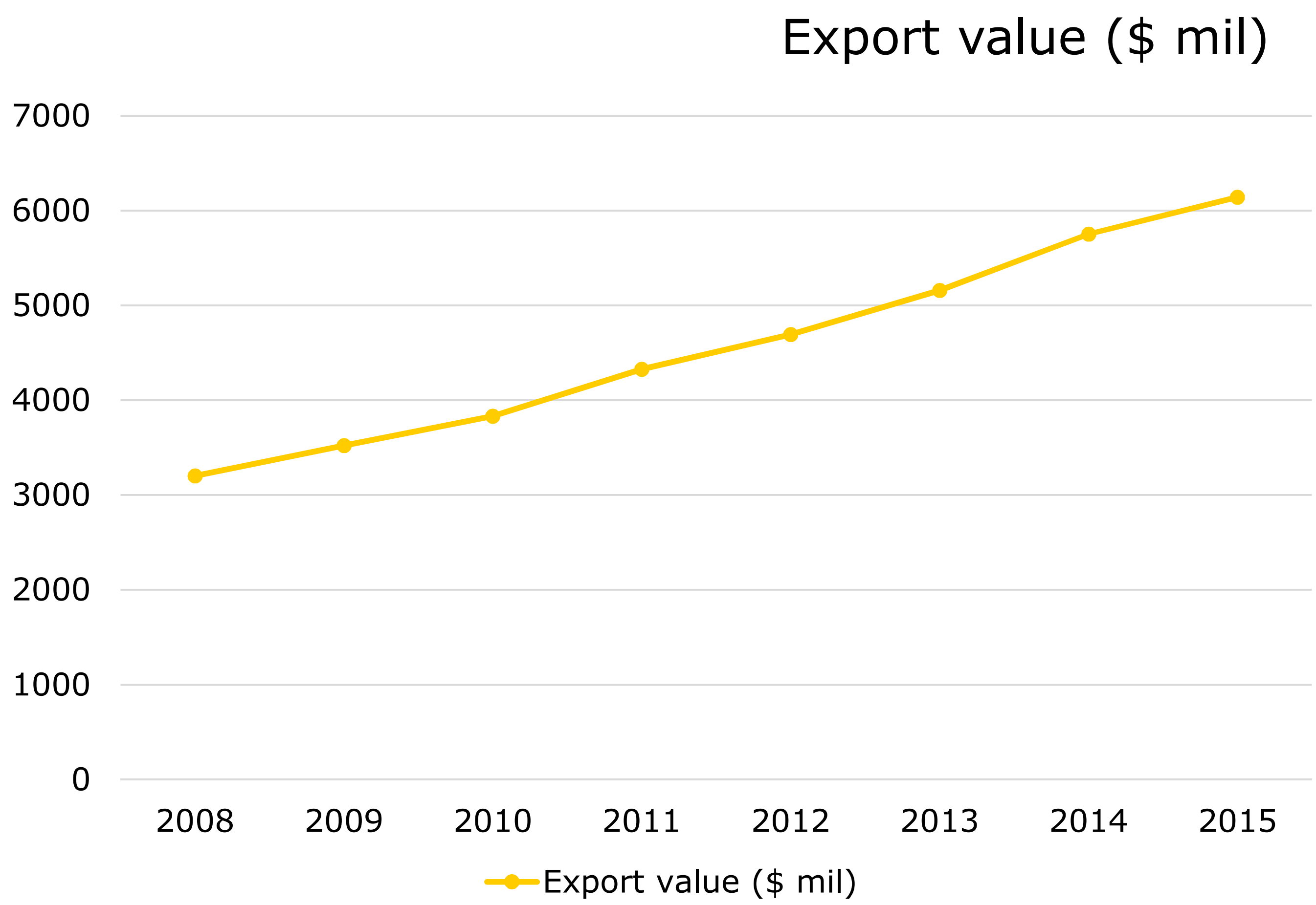
New Zealand Landscape

- Early 80s, New Zealand had more than 60 million sheep.
- 2011: New Zealand down to 31 million sheep
- The number of dairy cattle was up however to 6.2 million, 4 percent higher than 2010 - the dairy heard is now double the number it was 30 years ago.
- The amount of land planted in grapes has increased, up three per cent between 2009 and 2011.
- Another 7000 hectares of forest was planted.
- Agriculture, horticulture and forestry account for more than half of New Zealand's exports.




Forestry – increased export value

- 1980’s boom
- Increasing demands from China



Forestry – dangerous industry

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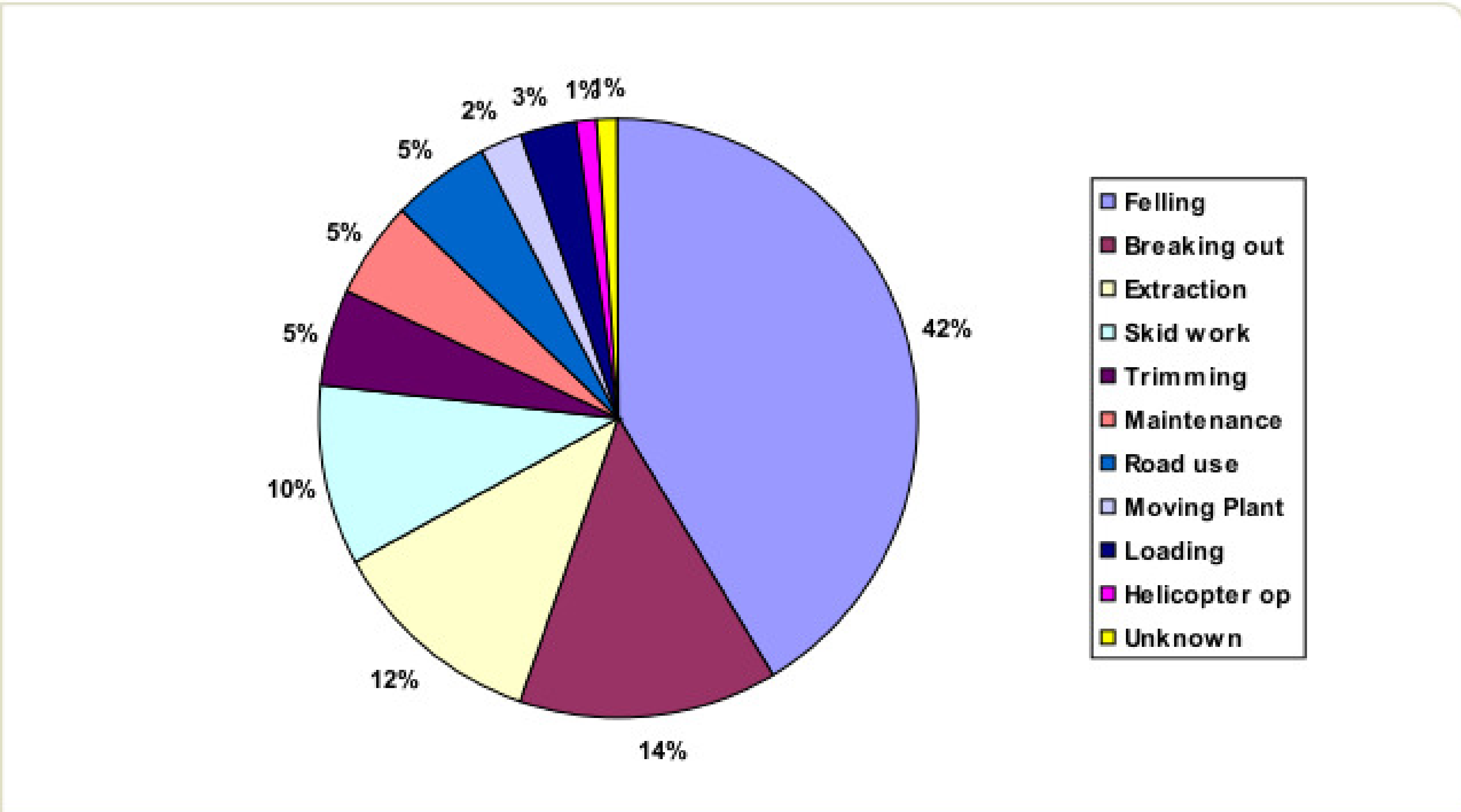
- 77% of harvest felled manually

➢ 42% of the deaths are caused while felling

Figure 3: Causes of Fatalities 1988 to 2005[26]

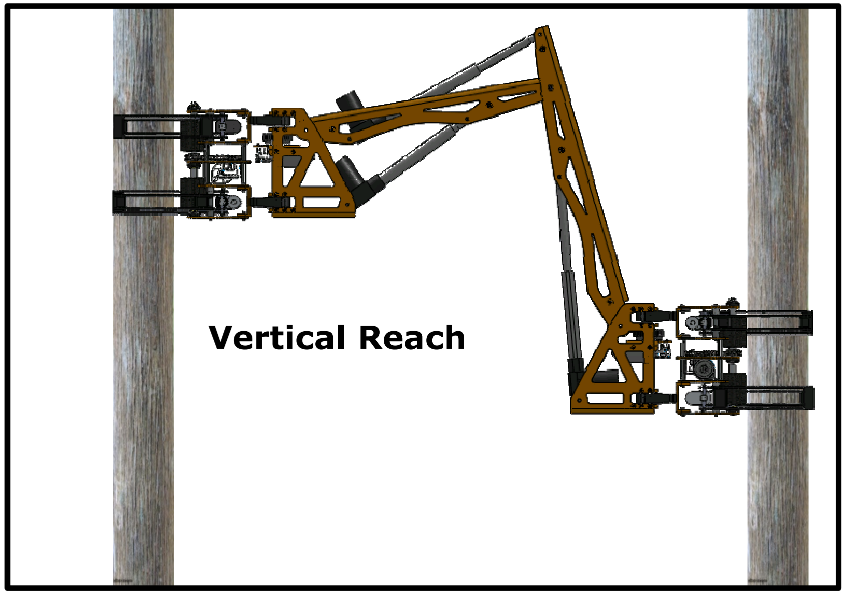


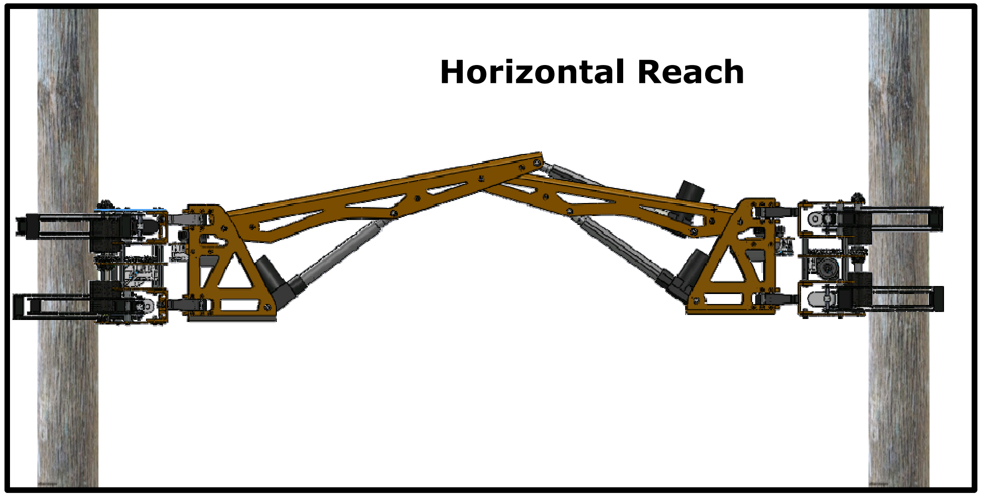
Robotisation of Forestry Harvest

- **Motivation**
  - To automate forest operations: felling, collecting.
  - To enhance safety
  - To increase the productivity
- **Research issues**
  - Machine mobility and stability on steep and soft soil country
  - Navigation of harvesting machines
  - Sensor fusion tele-operation
- **Challenges**
  - Highly unstructured, obstructive outdoor environment.
  - Steep and soft soil forestry peculiar to NZ.
  - NZ trees are big!

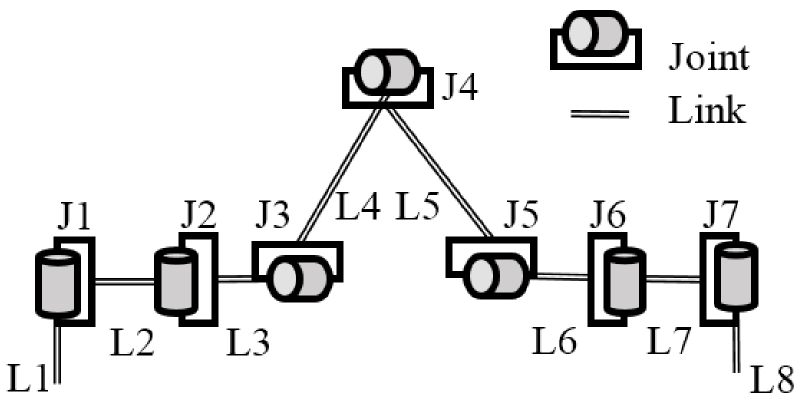
Source: Virtual Forest at ElmiaWood 2009

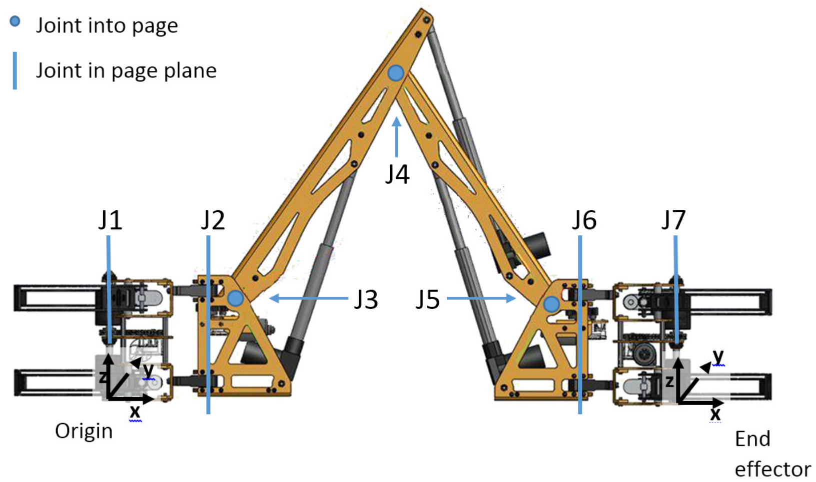
Proposed solution: Tree-to-tree Movement





Machine design





Machine kinematic model

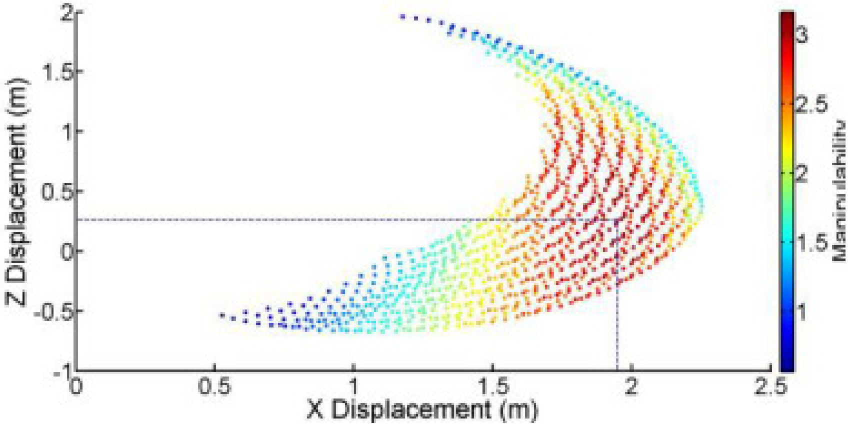
- Transformation between adjacent reference frames:

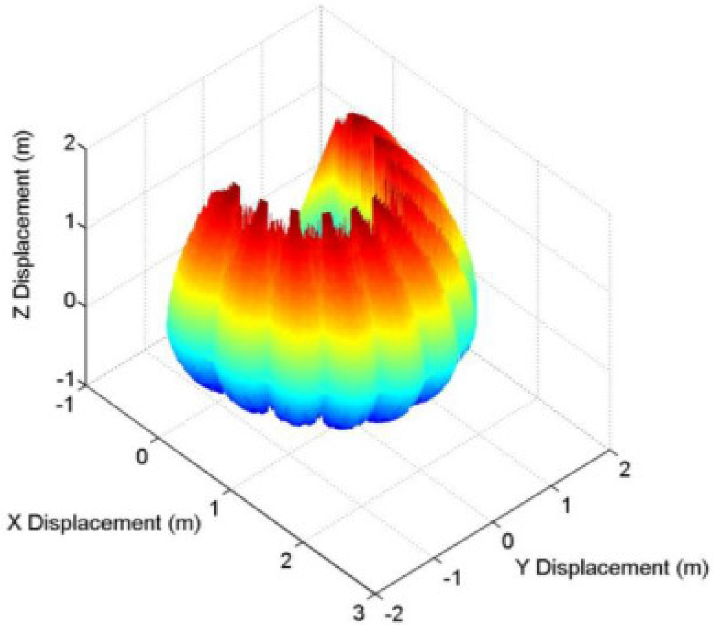
$$A_j^{j-1} = \begin{bmatrix} \cos\theta_j & -\sin\theta_j \cos\alpha_j & \sin\theta_j \sin\alpha_j & a_j \cos\theta_j \\ \sin\theta_j & \cos\theta_j \cos\alpha_j & -\cos\theta_j \sin\alpha_j & a_j \sin\theta_j \\ 0 & \sin\alpha_j & \cos\alpha_j & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Transformation between any two frames:

$$T_b^a = \prod_{i=a}^{b} A_b^a(q_b), \quad where\ b > a$$

Workspace & manipulability





Working Prototype

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Concluding Remarks

- A successful rocketry program supports both undergraduate teaching, postgraduate research and industry development.
- A novel wall climbing robot with sensor feedback control is commercialised. It offers reliability, high attraction force / weight ratio, reliability, energy efficiency.
- Biped robot offers an effective solution to mobility in steep forestry.
- Scientific and engineering breakthroughs have to come in robot's journey towards autonomous operation in natural environments.
  - ➢ Novel actuation / drive mechanisms to improve lifting capacity and manoeuvrability.
  - ➢ Adaptive and learning reinforced machine intelligence.
  - ➢ Robot-Robot/Human-robot collaboration, swarm intelligence.
  - ➢ Engineering innovation to bring the cost down.

Can mobile robots emulate the impact of PCs in 30 Years?